

Technical Support of the U.S. DOE Biomass Power Program in the Development of Biomass to Electricity Technologies.

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INTRODUCTION

In the United States, the period from 1973 to the present has shown a dramatic upswing in bioenergy use, especially in thermal and electrical applications of wood residues. The wood processing and pulp and paper sectors became about 70% self sufficient in energy in this period; and the amount of grid connected electrical capacity has increased from less than 200 MW_e in 1978 to over 7,500 MW_e today. This dramatic growth, stimulated in part by Federal tax policy and state utility regulatory actions, occurred after the Public Utilities Regulatory Policies Act (PURPA) of 1978 guaranteed small electricity producers that utilities would purchase electricity at a price equal to the utilities' avoided cost.

More than 70 percent of biomass power is cogenerated with process heat. Wood-fired systems account for 88 percent, landfill gas 8 percent, agricultural waste 3 percent, and anaerobic digesters 1 percent. There are nearly 1000 wood-fired plants in the U.S., typically ranging from 10 to 25 MW_e. Only a third of these plants offer electricity for sale. The rest are owned and operated by the paper and wood products industries for their own use. Most of today's biomass grid connected power installations are the smaller scale independent power and cogeneration systems. To date, utilities have been involved in only a handful of dedicated wood-fired plants in the 40 to 50 MW_e size range, and in some co-firing of wood and municipal solid waste in conventional coal-fired plants. Net plant heat rates for 25 MW_e plants in the California PG&E service territory average approximately 20 percent efficiency (17,000 Btu/kWh). By comparison the 43 MW_e utility-operated plant at Kettle Falls, Washington has a reported heat rate of 23.7% efficiency (14,382 Btu/kWh).

The advantageous power purchase agreements that were negotiated under PURPA in the 1980's are no longer available at high avoided cost rates. As a result a number of plants are closing as their power contracts come up for renewal. These plants could be competitive in today's environment using low cost waste and residue fuels if their efficiency was much higher. This has been demonstrated in the Hawaii sugar industry where the sugar mill power plants operate for a major part of the year as combined heat and power (CHP) installations. Investments in efficient steam cycles have resulted in a competitive rate of power generation under PURPA. Low pressure boilers were systematically replaced by higher pressure boiler systems of larger capacity in the period 1960 through 1980, with the average steam pressure and temperature increasing

from 1.3 MPa and 210• C to 4.4 MPa and 380• C. Meanwhile the net steam consumption in the mills decreased significantly from 600 kg /tc (ton of cane) to about 300-400 kg/tc; resulting in a power output of about 60 kWh/tc on average, with the best mills reaching over 100 kWh/tc.

Biomass power efficiency advances are needed to be competitive with low-cost fossil fuels, especially in stand-alone power generation. Such advances will require a considerable increase in the power-to-heat ratio and will require the use of advanced technologies, such as the use of IGCC (Integrated Gasification Combined Cycles), as illustrated in Table 1.

Table 1. Comparison of present day steam generation with IGCC

Cost factors (¢/kWh)	Steam Generation	IGCC
Operations and Maintenance	0.5	0.5
Fuel only Cost	3.6	1.6
Capital Recovery	4.2	3.0 -3.5
Cost of Electricity	8.3	5.1-5.6

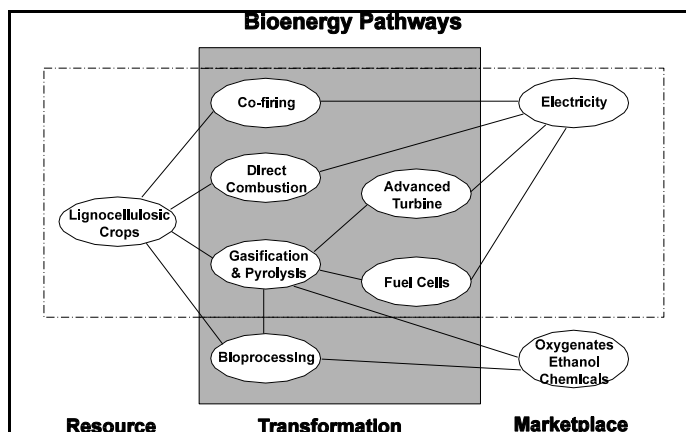
Assuming a marginal cost of fuel of \$2/million Btu (approximately \$40/tonne of dry biomass), a load factor of 85% (base loaded), and a return on capital invested of 8% per year, it is possible to see the effect of the new technology. Both plants are approximately 50 MW_e capacity. The efficiency of the steam plant is about 20%, while the IGCC is estimated to have an efficiency of 45%. The capital cost of the steam plant is \$1800/kW, while that of the IGCC is expected to be in the range of \$1300 to \$1500/kW. As can be seen, the increase in efficiency has two effects: it reduces the capital cost on a kW basis, and it reduces the sensitivity of the final cost of electricity to the fuel cost component.

USDOE BIOMASS POWER PROGRAM

The USDOE Biomass Power Program is working to address the issues of making biomass competitive by working with today's industry to increase its reliability and to develop advanced systems for increased efficiency and environmental performance.

The pathways under discussion are included in figure 1.

Support for today's Industry:



In general the biomass power industry has displayed good reliability; however, in the case of the independent power producer (IPP) biomass-fueled stations in California, operational difficulties rapidly emerged when using non-wood biomass fuels¹. The operational difficulties were caused by the deposition of mineral matter on heat exchange surfaces (boiler tubes, superheaters, and water walls) and by the agglomeration of ash and inert fluid bed materials. This problem is one that is costly as it results in down-time for tube cleaning and repair. Because there is considerable interest in the development of dedicated crops such as short rotation woody crops and herbaceous energy crops for bioenergy applications, it could be a problem that would affect the long-term large-scale deployment of biomass fuels in both electricity generation and the production of liquid fuels. For this reason the USDOE, through NREL, initiated a collaborative study with industry on the ash deposition problem² with the goal of establishing the root cause of the difficulties in using non-traditional biomass fuels.

While the nature of the direct combustion boiler problem is of current concern, NREL also recognized that these same issues may have to be addressed in non-combustion processes such as fast pyrolysis and gasification that convert biomass into intermediate fuels that for use in very high efficiency generation systems based on gas turbines. Gas turbines are extremely sensitive to both mineral matter and alkali metals. For the state-of-the-art turbines with turbine inlet temperatures of 1260• C (2300• F) the manufacturer's specifications call for less than 300 ppb of alkali metal in the hot section. Since high efficiency biomass-to-electricity conversion is a goal of the USDOE Biomass Power Program³ a program of testing non-woody and short rotation biomass feedstocks in gasifiers and fast pyrolysis processes was instituted.

The ash deposition problem was addressed by conducting extensive fuels and deposits analysis, and through an extensive collaboration the cause was identified. The project received over 700 different fuels analyses from the participants; however, the majority of these did not have the critical ash analysis data. This may not have been such a bad omission since the project established that there are major problems with the standard ash determination methods that are

¹Jane Hughes Turnbull. 1993 *Use of Biomass in Electric Power Generation the California Experience*, Biomass and Bioenergy Vol. 4. pp 75--84.

²Alkali Deposits found in biomass power plants: a preliminary investigation of their extent and nature. NREL Subcontract TZ-2-1-11226-1. Principal Investigator Thomas R. Miles of Thomas R. Miles Consulting Design Engineers. Participants: Delano Energy Company Inc.; Electric Power Research Institute; Elkraft Power Company (Denmark); Foster Wheeler Energy Corporation; Hydra Co Operations Inc.; Mendota Biomass Power; Inc.; National Wood Energy Association; Sithe Energies, Inc.; Thermo Electron Energy Systems; Wheelabrator Environmental Systems Inc.; Woodland Biomass Power Ltd.; Western Area Power Authority; Sandia National Laboratories; Hazen Research Inc.; Al Duzy and Associates; University of California Davis; U.S. Dept. of the Interior, Bureau of Mines; Appel Consultants, Inc.

³Electricity from Biomass National Biomass Power Program Five-Year Plan (FY1994-FY1998) Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, U.S. Department of Energy, Washington, D.C. Draft April 1994.

accepted as standards for coal materials. The ASTM methods for coal prepare an ash at 800• C which is then used for the pyrometric cone analysis to determine if there will be slagging or stickiness problems. Unfortunately, the critical element causing the ash deposition and fouling problem is potassium, and it is known that this and other mineral matter from biomass will evaporate from the ash at 800• C, decreasing its mass and altering its fusion properties⁴. Potassium is a key component of cellular function and in plants it can be present at 1000 times the concentration of sodium. As much as 35% of the ash in annual plants can be alkali, which drastically reduces the ash fusion temperature from greater than 1300• C in the case of wood ash to about 700• C. At this temperature the potassium can form a eutectic with the plant's silica or the sand medium of the fluidized bed⁵. Work with the molecular beam mass spectrometer (MBMS) system at NREL has shown that the form in which potassium is transported can be very diverse including oxides, hydroxide, sulphite, sulfate, and chlorides as volatiles⁶.

Gasification Developments:

Commercial biomass gasifiers are already in use to generate process heat and steam. Current development activities are focused on producing electricity and, to some extent, liquid fuels, and involve integrating gasification with various cleanup systems to ensure a high-quality and reliable gas product. At this time, there is no clear preference for a single gasifier system. The Global Environment Facility⁷, is evaluating two systems offered by Scandinavian commercial developers for the CHESF project in northeast Brazil. The evaluation will compare the advantages and disadvantages of using air gasification at high pressure (Bioflow) or at low pressure (the TPS system). High-pressure gasification would have to meet the pressure requirements of the chosen turbine on all system components, including the gas clean-up system; the low-pressure system would carry out the gas cleaning before compressing the fuel gas to the turbine operating pressure. Air blown systems produce only a low-heating value gas (less than 150 Btu/ft³, 5-6 MJ/Nm³); and a significant loss in efficiency is imposed if the gas must be cooled to ambient temperatures prior to being compressed. For this reason, the American and

⁴M.K. Misra, K.W. Ragland, and A.J. Baker. 1993 *Wood Ash Composition as a Function of the Furnace Temperature*, Biomass and Bioenergy Vol. 4. pp 103-116.

⁵A. Ergundler, and A.E. Ghaly. 1993 *Agglomeration of Silica Sand in a Fluidized Bed Gasifier Operating on Wheat Straw*, Biomass and Bioenergy Vol. 4. pp 135-147. See also the phase diagram for SiO₂ - K₂O.SiO₂ in E.M. Levin, H.F. McMurdie, and F.P. Hall, 1956. *Phase Diagrams for Ceramists*. The Am. Ceramic Soc. Inc.:Columbus OH.

⁶D. Dayton, and T.A. Milne. Alkali, chlorine, SO₂, and NO₂ release during combustion of pyrolysis oils and chars. in Ed. T.A. Milne. *Proceedings Biomass Pyrolysis Oil Properties and Combustion Meeting*. September 26-28, 1994 Estes park Colorado. NREL-CP-430-7215. pp 296-308

⁷P. Elliott, and R. Booth. 1993. *Brazilian Biomass Power Demonstration Project*. Special Project Brief. Shell International: London, U.K.

Scandinavian gasification programs are emphasizing the use of hot gas clean-up systems for the air-blown, low-heating-value gasifiers that will be operated at pressure.

The U.S. program has a dual-pathway strategy involving both low- and medium-heating-value gas production. One high-pressure system is capable of generating either low- or medium-heating-value gases according to whether it is an air- or oxygen-blown variant, and is the Renugas® system developed by IGT. The low-pressure strategy in the U.S. is based around two developers of medium-heating-value gas systems who do not use oxygen, but rather use indirect gasification to produce gases having heating values of 350-450 Btu/ft³ (15 - 20 MJ/Nm³). Cooling and quenching the gas does not incur a significant efficiency penalty, and compared with low-heating-value gas, there are essentially no modifications required in the turbine combustors to handle the medium-heating-value gas fuels.

The Pacific International Center for High Technology Research (PICHTR) Project (>6 MW_e):

The U.S. Department of Energy (DOE) and the state of Hawaii have joined with PICHTR in a cost-shared cooperative project to scale up the Institute of Gas Technology (IGT) Renugas® pressurized air/oxygen gasifier to a 45-90 ton/day engineering development unit (EDU) operating at 1-2 MPa using bagasse and wood as feed. The site is the HC&S sugar mill at Paia, Maui, Hawaii; NREL is providing project oversight in addition to systems analysis. The first phase, which is now being commissioned consists of the design, construction, and preliminary operation of the gasifier to generate hot, unprocessed gas. The gasifier is designed to operate with either air or oxygen at pressures up to 2.2 MPa, at typical operating temperatures of 850• - 900• C. In Phase 1, the gasifier will be operated for about four months at a feed rate of 45 ton/day at a maximum pressure of 1 MPa. Following the end of Phase 1 in late 1995, a hot-gas clean-up unit and gas turbine will be added to the system to generate 3-5 MW_e of electricity.

The Vermont Gasifier Project with FERCO and the McNeil Generating Station (>15 MW_e)

Future Energy Resources Company (FERCO) of Atlanta, Georgia, is the licensee of the Battelle indirect gasification system; and the scale up is at the site of the Burlington Electric Department's McNeil station in Burlington, Vermont. The project, which is in two phases, will first take feedstock from the 50 MW_e station and after gasification will return the gas to the boiler. The scale of operation is about 200 tpd. The second phase will incorporate approximately 15 MW_e of turbine electricity generation. The project is jointly funded by USDOE and FERCO and presently construction is forecast to start in Fall 1995.

National Renewable Energy Laboratory (NREL) Activities:

The research strategy is guided by systems analysis and technoeconomic assessments of gasifier-based power cycles. In the laboratory, research is ongoing to develop catalysts for hot gas conditioning and to use advanced instrumentation and chemometrics for feedstock characterization and evaluation. One element of this research is using advanced mass spectrometry to characterize alkali metal speciation under gasification and combustion of

biomass conditions. This work has been extended to develop and using a transportable molecular beam mass spectrometer (TMBMS) for real time measurement of hot stream composition to 500 atomic mass units (amu). The TMBMS is being used by both Battelle and IGT to measure gasifier and catalyst performance in the field.

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